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XXX.—*On the Zoological condition of Chalk Flints, and the probable causes of the Deposit of Flinty Strata alternating with the Upper Beds of the Cretaceous Formation.* By D. T. Ansted, M.A., F.R.S., Professor of Geology in King's College, London, and Fellow of Jesus College, Cambridge.

The occurrence of siliceous bands—the silex being exhibited in detached fragments called flints—regularly bedded with the upper portion of the Chalk formation in many parts of Europe has always been considered a geological phænomenon very difficult to account for, and the explanations hitherto offered have been extremely unsatisfactory, because they have assumed a mineral condition for the silica which we are not warranted by experience in supposing to be possible, and which no one who fairly examines all the circumstances of the deposit can at all conclude to be probable.

Dr. Buckland has supposed, for instance*, that each new mass of calcareous and siliceous matter as it was discharged formed a bed of pulpy fluid at the bottom of the then existing ocean, and that the separation of the siliceous from the calcareous ingredients was modified by attractions drawing the particles to certain centres. Dr. Mantell again in 1833 remarks†, speaking of a specimen of Ventriculite, "the appearance of this specimen seems to warrant the conclusion, that at the period of its mineralization the silex was in the state of a thick viscid fluid." And in 1838 Mr. Lyell, referring to Dr. Buckland's account already quoted, adds, "Nevertheless the separation of the flint into layers so distinct from the chalk is a singular phænomenon, and not yet accounted for. Perhaps, as the specific gravity of the siliceous exceeds that of the calcareous particles, the heavier flint may have sunk to the bottom of each stratum of soft mud."

I need hardly say more in illustration of my remark, that the origin of flints in chalk is a phænomenon not yet satisfactorily explained: nor, indeed, do I venture to assert that the view I

* Geol. Trans. 1st series, vol. iv. p. 422. The date of this paper is 1816.

† Geol. of South-east of England, p. 102.

am myself inclined to take, and which I am now about to advocate, is borne out entirely by positive observation. I think, however, I shall be able to offer a reasonable and probable account, and one more consonant with the results of minute investigation than any of those I have quoted.

Of the lithological and geological character of the chalk and the layers of flint imbedded in it I need say very little. Chalk itself is a nearly pure carbonate of lime, having a small quantity of iron as well as silica distributed through it, the particles of the former mineral being collected into nodules irregularly placed, and usually crystallized with sulphur in the form of pyrites*. Careful microscopical investigation has distinctly proved that a large proportion of the solid chalk is of animal origin, and the substance most nearly resembling it in a recent state is a white calcareous mud formed in coral lagoons by the decomposition of recent soft corallines. The flint in chalk consists of about 98 per cent. of pure silica, and is usually of dark colour internally, but each nodule or separate portion of a layer is surrounded with a thin coat of a white colour and a coarser or more saccharoid texture, evidently owing to the presence of a certain proportion of chalk. The flints occur either in detached nodules or tabular masses; the latter forming layers of various thickness alternating with a much greater though also variable thickness of chalk, and the former more rare and still having a tendency to stratified arrangement. Flints are also sometimes found filling up veins and traversing the chalk at various angles. Almost the whole however of the siliceous matter of the upper chalk is distributed in tabular masses, and it is chiefly therefore to those that I shall refer, although I may mention here, that there is no apparent difference in structure between the tabular flints and those which occur detached or filling up veins.

In order to discover the conditions under which siliceous matter may have formed in the chalk, and the cause of its appearing in layers regularly stratified and distinctly separate, it is clear that we must investigate minutely not only the chemical condition of the mineral, which is a very insufficient guide, but also its mechanical condition; and this must be done in two ways, examining first its structure by the aid of a powerful microscope, and then observing its external relations both with the chalk itself and also with the organic bodies imbedded in it. We must also pay some attention to the nature of those silicified fossils of whose organic origin there can be no doubt.

* A small proportion of argillaceous matter occurs in the lower chalk, but this proportion is smaller as we examine specimens higher up in the formation, until at length in the white chalk with flints it can no longer be traced.

It is to Professor Ehrenberg that naturalists are indebted, first for the discovery of the infusorial and other animalcules of the chalk, and next for the determination of various organic remains in the solid substance of flint. These observations induced Mr. Bowerbank in 1840 to examine with care numerous specimens of chalk flint, and in doing so he was struck by the frequent recurrence of small patches of brown reticulated tissue constantly presenting nearly the same appearance. "The occurrence of this tissue," he observes in a paper published in the Transactions of the Geol. Soc. (2nd ser. vol. vi. p. 181), "combined with the circumstance of finding spicula exhibiting nearly the same form and size, and always occurring in about the same proportion along with numerous foraminated shells and other extraneous bodies, strongly induced me to believe that the brown reticulated tissue was a portion of the remains of the organized body, the shape of which was represented by the flint nodules; and the indications thus observed equally inclined me to believe, that if these flints were fossil organized bodies, they would almost inevitably prove to be sponges." On the careful examination of a considerable number of flints obtained from various localities, he found in all a perfect accordance in the structure and proportion of this tissue and of the spicula. I proceed to give a short account of the result of these experiments.

When thin slices of flint are examined under a good microscope as transparent objects with a power of 120 linear, they present the appearance of a turbid solution of decomposed organic matter, containing fragments of extraneous bodies and portions of a dense opake matter of a brown colour and sometimes of considerable size. Treating these latter as opake objects, they are readily distinguished to be made up of numerous cylindrical contorted canals with occasional orifices of larger diameter, the walls of the canals presenting an appearance of having been formed of thin network like that observable in sponge, while spicula and minute foraminated shells are sparingly distributed over the whole. The smaller of the canals correspond with those by which the animal of a sponge introduces the sea-water into its substance, the larger ones being those for the excretion of the water.

But this is not all. Even when the reticulated tissue is not to be traced, its presence is still often indicated either by the form in which the silex is moulded upon the tissue once there, or by the spicula and minute shells which are suspended equally in all parts: not being precipitated to one particular portion, as if they had been deposited in a fluid, but entangled in the organized matter, which had retained its form and texture during the process of silicification. An examination of the chalky band forming the exterior of the flint also exhibits a peculiar appearance under the microscope, deep circular excavations being traceable, and small fragments of shells and other extraneous matters being partly imbedded in and partly adhering to the surface.

Mr. Bowerbank having thus examined and described the nature of the flint which forms tabular masses interstratified with the chalk, extended his observations to the internal casts of sea-urchins and other shells of Radiata common in the chalk, some of which are wholly and others only partially siliceous. In these cases, on clearing away the chalk with care, it appeared that the flint did not in any case present an even surface, such as would have resulted from a fluid depositing the siliceous matter, but, on the contrary, that the surface was undulated, projecting above the surrounding parts, and offering the same characters as those observed in flint nodules. It therefore appeared that these remains must be referred to the same origin as the tabular flint.

Mr. Bowerbank, from such observations as these, has arrived at the conclusion, that all flint, in the common acceptation of the term, has been formed upon spongeous bodies as nuclei. Anxious to verify so far as I could these conclusions and convince myself of their correctness, I have now to record an observation of my own of a similar kind.

In this experiment, which I look upon as to a certain extent an *experimentum crucis*, I selected from the collection in the Woodwardian Museum* a small specimen of the purest black flint, in which a common *Cidaris* of the chalk was imbedded, part of the shell projecting beyond the surface of the flint and that part still consisting of carbonate of lime. The general appearance of the specimen is strongly in favour of the idea of a pulpy tenacious fluid having received on its surface the sinking shell, whose weight was not sufficient to cause it to sink entirely beneath the surface.

Examining first of all fragments of the flint not contained within the shell, they presented the appearance described by Mr. Bowerbank and figured in the Geol. Trans.; they did not indeed exhibit distinct marks of reticulated tissue, but there could be no doubt whatever of their organic origin. I then selected several small portions chipped off from within the fossil, and one of these, although exceedingly minute, was fortunately sufficiently uniform in its texture to admit of employing a very high power. I was thus enabled clearly to distinguish the peculiar reticulated tissue, the existence of which puts beyond question the nature of the organized being upon which this portion of the silica had formed. The distinct texture was not made out without a power of 1200 linear, and the appearance was still more striking with a power of 2500. In this case then, the substance which has partially filled a shell not broken and resting on the surface of a flint, is itself of the

* The Geological Museum in the University of Cambridge.

same spongeous origin as the flint on which it reposes. The surfaces however within and without this shell are not on the same level, but the flinty matter has reached considerably higher on one side than on the other, and has entered the shell on the side opposite to that on which it has the highest surface. This latter fact is clear from the perfect condition of the shell. But we cannot suppose a thick pulpy fluid to have entered the shell at its lower part and have risen in it on the opposite side above its general level, although there is no difficulty in conceiving that a sponge so entering an inclosed space should work its way upwards in the endeavour to reach the open water.

With regard also to the surface of the flint and its partially calcareous appearance, it is readily explained, if we suppose the flint to have been originally a sponge; in that case a deposit of calcareous mud taking place upon it would penetrate only to a very small depth, while the interior space would remain filled with pure water. By far the greater portion of the sponge would thus be preserved from the operation of other agents while the process of silicification was going on, provided it is the case (as we have every reason to suppose) that the silex forms readily on such horny organic matter as is found in all sponges.

The conclusions thus arrived at as to the origin of tabular flint are greatly strengthened when we consider the nature of the commonest chalk fossils that occur silicified, and the peculiar appearances often presented by chalk flints.

By far the most abundant of those fossils in the chalk which attain to any size are the remains of spongy Zoophytes, known under the generic names of *Ventriculites, Choanites, Paramoudra* and *Polypothecia.*

The *Ventriculite* is found of various shapes and sizes, and its original texture was evidently soft, and yielding readily to pressure. It appears to have possessed externally a reticulated surface, the inside being porous and bearing considerable resemblance to dried sponge. Specimens occur in every intermediate form between that of a simple elongated cone and a flat circular disc, the thickness of the sides being considerable when the cone is short, thinner when more extended, and thinnest when completely expanded.

The *Choanites* differ from *Ventriculites* by the possession of a circular opening in the upper part, which continues gradually diminishing to near the base. The general proportions are also somewhat different and the dimensions smaller.

The *Paramoudra,* or Potstones, are only common in particular localities; but there attain a considerable size, measuring from one to three feet in height, and about half that in diameter. They are chiefly found in the North of Ireland and in chalk-quarries near Norwich, and are generally insulated in the chalk, sometimes lying horizontal and sometimes inclined or erect, but although silicified, not apparently connected with the layers of flint. These singular fossils are cylindrical, fusiform or cup-shaped, and they are occasionally found planted as it were one above another, the upper one being closed at the top and attached to the open lip of that immediately below. They all have a hollow open axis filled with chalk, and a central tube about the thickness of a finger, and consisting of siliceous particles, is traceable through the chalk from the base to the vertex*. All these three genera were doubtless affixed by radicles to solid rock and possessed no powers of locomotion.

Lastly, the *Polypothecia* represented the branching sponges as the former genera did the large cup-shaped sponges of the existing seas. They are frequently found inclosed in flint, the *Polypothecia* having in this case been partly surrounded by another sponge and silicification taking place in the whole mass together. The branching sponge however not decomposing at the same rate as the other, we often find its remains represented by a loose cast in the substance of a common flint.

It appears then, that in the zoological condition of those flints which offer external proof of their organic origin as well as in the microscopic structure of the others, which are regularly stratified in tabular masses, the principal, if not the only, accumulations of siliceous matter in the chalk are upon sponges; that singular class of organic beings, the very fact of whose possessing life has sometimes been doubted. It only now remains to consider how far the external relations of such fossils with the chalk itself renders it probable or otherwise that all chalk flints are of spongeous origin.

In those cases in which the flint is perfectly tabular, these relations can of course have no further interest than that which arises from the condition of the surface of the flint which we have already considered; but it is not an uncommon accident that portions of some organic bodies should adhere to or be imbedded in the flint, sometimes projecting from it to a considerable distance and offering strange and grotesque forms. Such appearances are easily explicable on the hypothesis of sponges growing at the bottom of an ocean, in which from time to time various fragments of shells, &c. were deposited and partly inclosed by the sponges; and it is not at all necessary to assume that these fragments were

* The organic nature of the siliceous matter in the *Paramoudra* is sufficiently clear from the evidence of Prof. Ehrenberg on this subject. He states, that although he failed to discover in them the structure of well-preserved sponges, he could perceive the contorted remains of decomposed sponges along with the remains of Infusoria.—Annals of Nat. Hist. vol. ii. p. 162.

received upon a mass of semifluid siliceous matter, without the existence of which it has hitherto been thought impossible to account for the phænomena. The microscopic structure is in all these cases precisely the same, and the evidence is therefore conclusive.

And finally, the composition of the chalk itself and the nature of its organic remains, requiring as these do the lapse of a long period of time, may be considered to strengthen the probability of the organic origin of the siliceous part of the formation. There is, we know by experience, a tendency in different substances, when distributed irregularly, to accumulate round certain points of attraction, and by the process of segregation separate themselves even from others with which they are in contact, and this is still more the case when any particles of the same substance as that about to be grouped are present in any part of the whole mass. Sponges are known to contain siliceous spicula which also are constantly seen in chalk flints, and thus we have additional grounds for supposing that the layers of flint were formed upon spongy bodies as their centre.

It is only necessary now in conclusion to put into general language the view which results from the considerations I have offered with reference to the internal structure and external appearance of chalk flints, and their relations with the fossils of the chalk and with the chalk itself.

I suppose that for a long period the gradual deposit of chalk may have gone on undisturbed, the material being derived partly from animals living in the water at the time, and partly, perhaps chiefly, from the degradation of calcareous and coralline rocks at a distance, the silt being conveyed by marine currents and evenly deposited. In this way I presume that the formation of the lower and middle chalk may be fairly explained. At the termination of these deposits I imagine that there succeeded a period of tranquillity, the cretaceous mud ceasing to be deposited, and the bottom of the sea becoming hard and fit for the habitation of innumerable sponges, which lived and flourished there. In these we see, as I believe, the elements of the first layer of flint in the chalk, and I suppose that after they had continued to exist for a certain time, there occurred the commencement of a series of subterraneous disturbances in some part of the bed of the ocean of the nature of undulations, elevating the bed of the sea in some parts and depressing it in others. These disturbances I also suppose to have been accompanied by the eruption of a considerable quantity of hot water holding silica in solution*. The elevation

* The boiling springs of the Geyser in Iceland contain 31·38 grs. of silex per gallon of water, and even the mineral waters of Bath contain 20 grs. in ten pints and a half.

of calcareous beds, the previous denudation of whose exposed surface had formed the lower and middle chalk, would now again be the source of similar deposits, and the sponges would begin to be covered by a calcareous mud, and at the same time the siliceous matter would begin to deposit itself upon the organized substance of the sponges. After an interval corresponding to the deposit of the first layer of chalk above the flints I suppose another pause to have occurred, and a similar growth of sponge to have taken place and been succeeded by other disturbances, and so that such alternations of tranquillity and volcanic eruption continued till the close of the cretaceous period.

Without some such cause, I cannot see any reasonable explanation of the fact, that while flints and siliceous matter are found abundantly in other beds and under various circumstances, it scarcely ever occurs in layers, except in a certain part of the cretaceous system, that part not presenting any other difference whatever, either mineral, geological or zoological, with the immediately preceding strata: neither can I in any other way account for the fact, that single layers of flint and chert occur in other formations*, but not such alternations of flint and calcareous matter as we find in the chalk, although the origin of the flint appears to have been the same in all cases.

And finally, I am not assuming in these alternations and periodical eruptions any extraordinary or improbable agent. Immediately subsequent to the cretaceous period, and even during its continuance, we have the most decided proof of the action of disturbing forces on the grandest scale—forces to which we owe the disruption of the chalk in the Wealden district, and the positive and complete denudation of strata several hundred feet thick and many thousand square miles in extent, and disturbances, which in the North of Ireland and elsewhere were accompanied by the eruption of igneous matter to an extent rarely if ever since equalled.

I am also entitled to assume not only the possibility but the probability of the eruption of hot water containing silica in solution, and it is not impossible that this may have gone on constantly and without interruption during the whole period; while with regard to the existence of other calcareous rocks to whose denudation the chalk is owing, I have only to point to the absence of calcareous rocks overlying the beds in the West of England, and the fact that many oolitic outliers of limestone occur distant from the main formations, but bearing marks of

* In the freestone of Portland, in the mountain limestone of the Mendip Hills, in the oolitic limestone of Pickering in Yorkshire, near Poligny (on the north-west of the Jura mountains), and in the greensand of Black Down, &c.—See Geol. Trans. 1st ser. vol. iv. p. 420.